

Lean Production in the Japanese Shipbuilding Industry?

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ABSTRACT

The adoption of 'lean' automobile manufacturing concepts developed by Toyota has been advocated as a means to achieve large improvements in the performance of various other industries, including shipbuilding. The basic goal of lean production is cost reduction via elimination of unnecessary operations, waiting times, and inventories. This goal is self-evidently applicable to any business environment. However, there are specific mechanisms associated with lean production, and their applicability to shipbuilding is not as clear. Has lean production been a significant influence in Japanese shipbuilding? Are Japanese shipbuilders 'lean producers?' And is the lean production automobile model the appropriate approach to shipbuilding, or is some other package of best practices more applicable?

We approach these questions in two ways. First, we consider the relation of lean principles to production processes in the Japanese shipbuilding industry. Then, we describe two recent cases of process improvement in a Japanese shipyard and we discuss the extent to which these reflect lean principles. We propose that if lean production is considered as a general philosophy or set of goals, then the Japanese shipbuilding industry would likely rank ahead of Toyota in terms of achievement. On the other hand, considering the specifically 'lean' mechanisms derived from the automobile industry experience, it appears that not all are applicable to Japanese shipyards.

INTRODUCTION

'Lean production' is a term used in the United States to describe the automobile manufacturing system developed by Toyota. Taiichi Ohno, widely credited as a key developer and promoter of this system, stated that its objective is cost reduction (Ohno 1988, pp. 8-9). Another Japanese source amplifies this, stating that under the Toyota system, 'all company-wide improvement activities must directly contribute to the goal of cost reduction' (Japan Management Association 1989, p. 30).

At Toyota, Ohno focused attention on the need to eliminate inefficiency ('waste') throughout the manufacturing system. He targeted the following for special attention: overproduction, waiting time, transportation, processing, inventories, movement, and defects (Ohno 1988, pp. 19-20, 129). This is an instructive list; it includes processing itself, not just

transportation, waiting, and the other steps that have commonly been described as intrinsically 'non-value-added.' Ohno's principles may be summarized as cost reduction via the elimination of:

- Unnecessary operations
- Waiting times
- Inventories

The term 'lean production' was coined by a member of the research project that led to the best-selling book *The Machine That Changed the World* (Womack et al 1991). Although this book makes it clear that 'lean production' is synonymous with 'Toyota production system,' the more generic label can be helpful when it is desired to focus attention on concepts rather than their origin or a specific application.

What are these concepts? In *The Machine That Changed the World*, the top-level lean principles are

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teamwork, communication, efficient use of resources and elimination of waste, and continuous improvement. However, the authors maintain that Toyota's system cannot be reduced to a bulletized list of individual ideas, many of which Toyota did not originate. In their view, Toyota's accomplishment 'lay in putting all the pieces together to create the complete system of lean production, extending from product planning through all the steps of manufacture and supply system coordination on to the customer' (Womack et al 1991, p. 277).

In a follow-on book, Womack and Jones (1996) speak of five general mechanisms of lean production: (1) defining value for each product, (2) eliminating all unnecessary steps in every value stream, (3) making value flow, (4) knowing that the customer pulls all activity, and (5) pursuing perfection continuously. There are many other descriptions of lean production available; an excellent overview of the history and literature of this subject may be found in Cook and Graser (2001). A good source for those seeking more explanation of the development of Toyota's production methods is Fujimoto (1999).

Lean production and shipbuilding in Japan?

Ohno's goal of cost reduction through the elimination of unnecessary operations, waiting times, and inventory is self-evidently applicable to any business environment. 'Elimination of waste' is not a new idea and it has been argued that the Toyota production system (lean production) is essentially a variant form of Fordism or Taylorism (see, for example, Adler 1993, 1995).³

We will set this debate aside for now, and focus on the stated principles or mechanisms of lean production and how they apply to shipbuilding. Has lean production been a significant influence in Japanese shipbuilding? Are Japanese shipbuilders 'lean producers?' And is the lean production automobile model an appropriate approach to shipbuilding?

These questions will require much further work; here, we begin an approach to them in two ways. First, we consider how lean principles relate to actual Japanese shipbuilding practice. Then, we examine two cases of process change in a Japanese shipyard and we discuss the extent to which these changes reflect a movement towards 'lean' principles.

LEAN MECHANISMS AND JAPANESE SHIPBUILDING PROCESSES

For this discussion, we will take the basic mechanisms of lean thinking as those discussed by Womack and Jones (1996):

- Product value
- Elimination of inessential value stream operations
- Flow
- Pull
- Continuous pursuit of perfection

Product value

As final product value is determined in the marketplace, a key lean principle is to understand the nature and degree of value that the market demands in order to avoid incurring costs not justified by corresponding increases in market value. Achieving an effective cost/value relationship is not a simple matter for firms such as car companies, who design and manufacture mass-produced consumer products.

It was shown just how difficult this could be in the late 1980's to early 1990's when the leading Japanese automakers (including Toyota) ran into problems delivering value commensurate with cost. At that time, the cost structure of the industry suffered due to excessive product variety, unnecessary options, over-specification, and 'overquality.' This syndrome was known as 'fat design' and is described in Fujimoto (1999, pp. 207-222) and Womack and Jones (1996, pp. 237-238).

Such problems in identifying and specifying product value seldom arise in international commercial shipbuilding. Because merchant ships are capital goods rather than consumer products, shipowners can determine the value they require based on comparatively rational business criteria. Furthermore, as merchant ships are built to order under contract, the owner's requirements are communicated to the shipbuilder in a straightforward manner.⁴

Removal of inessential operations from the value stream

Since the post-war era, the elimination of unnecessary process steps has been a primary operational goal in the Japanese shipbuilding industry and in this respect Japanese shipbuilders can be considered one of the world's best examples of lean thinking in action. However, the extent to which these process improvements can be attributed to 'lean production' rather than classical Taylorism or Fordism depends on the specific motivation and details of each process initiative.

³ The Taylorist origins of other aspects of Japanese manufacturing management, including quality control, are documented by Tsutsui (1998). For primary source material on Taylorism and Fordism, see Ford (1926) and Taylor (1911)

⁴ As far as the authors are aware, the only case of an international merchant shipbuilder who has routinely built on speculation is Incat Australia Pty. Ltd.

The Japanese shipbuilding industry has historically approached production process improvement by:

- Increasing the speed of essential process steps.
- Eliminating unnecessary process steps and waiting time.

For the essential process steps that are to be speeded up, the idea is to reduce net working time by increasing the speed of physical production. Depending on the case, this is done via improved facilities, tooling, work methods, or other means. This requires detailed analysis of every activity in the shipbuilding process.

The unnecessary process steps and waiting times would be labeled 'waste' in the jargon of lean thinking. Three examples of the removal of inessential operations:

- Improvements in accuracy control to eliminate processing required due to extra material at the block joint.
- Training of multi-skilled workers to minimize idle time.
- Development of composite outfitting drawings to eliminate rework in engineering and production.

It can happen that a discrete shipyard process improvement will simultaneously increase the speed of an essential process step and also eliminate some other operations and/or idle time. For example, the introduction of line heating in the early 1960's increased the speed of plate forming, and also reduced downstream fitting work.

Many lower-level Japanese shipbuilding process improvements are the result of worker initiatives and this conforms to the spirit of lean thinking. Although most result in small gains, their overall effect is valuable. A case study of how worker-initiated process improvements are managed in a Japanese shipyard is provided in Koenig et al (2000).

Large, discrete process changes in Japanese shipyards are generally the result of engineering process analysis and technology development. Thinking that can be described as classically 'lean' inspires some of these process improvements. Others are motivated by the need to reduce costs through:

- Substitution of capital for labor.
- Reduction in the skill content of shop-floor jobs.

These last two motivations are more in the spirit of Frederick W. Taylor and Henry Ford than Taiichi Ohno.

Flow

The lean ideal here would be continuous one-piece flow of intermediate products rather than batch production. It could be argued that this is achieved in Japanese shipbuilding to about the same extent as in the auto industry.

In Japanese shipyard production, flow is based on blocks. Production processes (including cutting, subassembly, and assembly) are carried out block by block. Even when similar blocks are being built, their components are fabricated block by block and are not processed in batches covering several blocks. Although exceptions exist for plate nesting and for certain small standard components, the process is organized largely along a flow rather than a batch paradigm.

On fixed platens, subassembly and assembly work using a 'takt' method can typically be observed. Here, for example, welders move from platen A to B after fitters have moved from B to C. This gives an initial impression of batch production. But each platen is equipped with the same machines and tools, and the different work teams move from one to the other in sequence. This is a shipbuilding version of a 'conveyor' system, the difference being that the workers do the moving. But the flow principle remains in force.

Flow production is very plainly visible in the steel fabrication shops of Japanese shipyards. In fact, the potential benefits of 'flow' are so great that every attempt is made to achieve flow elsewhere as well, even in the erection dock. There have been instances of erection blocks being to some extent stockpiled near the dock to be ready to maintain workflow on the next ship, after the current hull is floated out. Such build strategies are the result of a trade-off between conflicting desires to maintain flow and low work-in-process inventory.

The organizational structure of Japanese shipyards reflects one-piece flow. This structure, explained in some detail in the classic National Shipbuilding Research Program reports of the late 1970's and early 1980's, is based on zone rather than function. In terms of lean theory, the zone system eliminates the activities of sorting and buffering and creates smoother interfaces between tasks.

Pull

Whether or not a pull system (just-in-time or 'kanban') is observable in shipbuilding or in automobile manufacturing, depends on the stage or level of the production process being considered.

At the top level of the business, the automobile industry has historically operated by producing inventory for sale. For years, 'mass customization' has been a goal but so far (at least in Europe and America) the majority of cars are still not built to order (Economist 2001). In the North American market, 30 days inventory of cars is considered effective and production is scheduled in accordance with demand forecasts.⁵ Given the top-level production schedule, however, the lower levels of the

⁵ Koenig, conversation with John Allen (TSD, Lexington, Ky.) at NSRP meeting, 18 April 2002, Williamsburg, Va.

production process (at least in the final assembly plant) can evidently be organized by pull as Toyota's example shows.

In terms of pull, merchant ship production is different from automobile production. Ship production is driven by pull at the top but by fixed schedules at lower levels. At the top level, the shipyard's production is based on the pull concept, as the shipowner's order pulls the final product and the shipyard is contractually obligated to deliver. It is not possible to start erection before the previous ship launches (or, in tandem construction, moves to the next position). There is thus a pull-style physical constraint preventing over-production at the uppermost level stages.

However, from the erection schedule on down, Japanese ship production is based on schedule development and conformance rather than pull. Schedule adherence at all levels of the production process is the paramount goal of production management in Japanese shipyards. Even if the next downstream stage drops a little behind, the upstream schedule is not allowed to slip. This is contrary to lean theory. Furthermore, when the occasional schedule-impacting production problem occurs in a Japanese shipyard, workers have no Toyota-style authority to 'pull the cord' and halt production until the problems are sorted out. Upstream work must continue regardless of a downstream problem, while special action is undertaken to make up for the delay without affecting other operations.

This strategy works well in Japanese shipyards because (1) 'takt' time is long compared to assembly-line mass production, and (2) production processes are accurately tracked using work progress reporting via the yard's CIM system and, at a more immediate level, by visual inspection in the shops. Long 'takt' time and effective process control enables management to correct problems by scheduling overtime and by shifting multi-skilled workers. In this manner, the original production schedule is recovered and the original contract delivery date is maintained.

To summarize: The Japanese shipyards' production management system is based on strict schedule adherence. It allows for no upstream slow-down when temporary downstream bottlenecks occur, nor for line stoppage to correct problems. Line stoppage is not tolerated because, in contrast to the situation in automobile final assembly plants, product is delivered under a contractual obligation and there is no sales or buffer inventory at the end of the line.

Continuous pursuit of perfection

In this respect Japanese shipbuilders are without doubt second to none. Their motivations, mechanisms and

achievements in this area are comparable to what is seen in the automobile industry.

Who was the original leader in lean thinking, Toyota or the shipyards?

To the extent that 'lean-ness' is associated with industrial competitiveness, it is worth recalling that the Japanese shipbuilders achieved global dominance before the car companies were even marginally competitive.

The Japanese shipbuilding industry moved up to first place in world ship production in 1956 (Chida and Davies 1990, p. 106). At that time, Japanese cars were high cost, rough products that were not sold outside their protected domestic market. Not until the late 1960's could the car companies' product offerings and cost structures meet the international industry standard (Cusumano 1991, p. 131).

Japanese shipbuilders have thus had no historical need to study and emulate Toyota. On the contrary, whatever flow of knowledge existed may possibly have been in the reverse direction. But this conclusion awaits further historical study.

Next: Two production process improvement cases

In the following two sections, we will review two production process changes that have been recently introduced in Japan. Both required considerable investment and represent examples of discrete improvement in shipyard industrial engineering. Do they show lean thinking at work, or some other dynamic?

UNIT PANEL AND SLIT PRODUCTION

In the early 1990's, shipbuilding market researchers predicted that by the end of the decade a boom in VLCC orders would take place. The reason: a large number of VLCC's had been built in the tanker boom of the early 1970's and such ships would be reaching the end of their economic life. Furthermore, IMO was phasing in the use of double-hull tankers and this would add to the pressure on shipowners to order new tonnage. At the same time, owners were demanding larger containerships than had ever been built.

To prepare for the upsurge in orders for very large ships, Japanese shipbuilders (the seven majors and also some of the medium-sized firms) undertook a range of improvement programs covering virtually all aspects of the ship design-build process. Considerable attention was directed to the improvement of basic shop facilities and construction methods. An example of this was the introduction by IHI of the new 'unit panel and slit' process (Okumoto et al 1992, Kashima et al 1997).

Problems with older methods

Today, conventional flat panel assembly processes use some variant of either the longitudinal pre-welding system or the egg crate system. These conventional methods are explained in the classic early-1980's reports of the National Shipbuilding Research Program and in the standard textbook by Storch et al (1995).

The longitudinal pre-welding method is attractive because of the long, straight welds used to attach the longitudinals to the plate. However, the provision of collars requires additional processes in design, material arrangement, cutting, manual mounting operations, welding, etc. These added processes are a 'non-lean' drag on productivity. Furthermore, it is difficult to automate the mounting and welding of the collar plates.

The new unit panel and slit process

IHI (and several other Japanese shipbuilders) are now using the 'unit panel and slit' method in flat panel assembly. The two basic characteristics of the process are:

- A re-ordering of sub-processes such that flat, stiffened panels are built up on single plates ('unit panels') instead of joined plate subassemblies
- Implementation of collarless ('slit') construction

In the unit panel and slit process, the first joining step is to weld longitudinals to a single shell plate, or 'unit panel.' Then, unit panels are joined to create panel blocks. On a separate line, the deep transverse subassemblies are produced. These have accurate slits cut in them that conform closely to the profile of the longitudinals. In the final step, the transverses are slid into place on the panel blocks, with the longitudinals

passing through the slits in the transverses. This is diagrammed in Fig. 1. Figs. 2, 3, and 4 show the process in action at IHI's shipyard in Kure.

What is essential in this process is not only the accuracy of the slit cut but also an effectively mechanized unit panel line for accurate placement of the longitudinals, well controlled heat input in welding, effective roller press fairing after welding, and other factors. The principal benefits of the unit panel and slit method follow the spirit of 'lean thinking':

1. The single plate + longitudinals, or 'unit panel,' is an extremely common element that forms part of the hull structure of virtually every ship design IHI builds. This means that lower-level commonality is increased and flow production is better maintained across product lines.
2. As the new unit panels have much more commonality than the old multi-plate panels did, the time required in assembling them is much more uniform. This facilitates a 'takt' approach.
3. The width of the plate is only about 1.5 to 4.5 meters, which allows the production machinery (high accuracy longitudinal placement machines, welding machines, and press rollers for fairing) to be mounted in a compact arrangement with short-span gantries. If the old concept of initial plate joining were used, the span required would be over 25m and practical implementation would be difficult.
4. Elimination of collars makes it feasible to do fully automated welding of large assemblies.

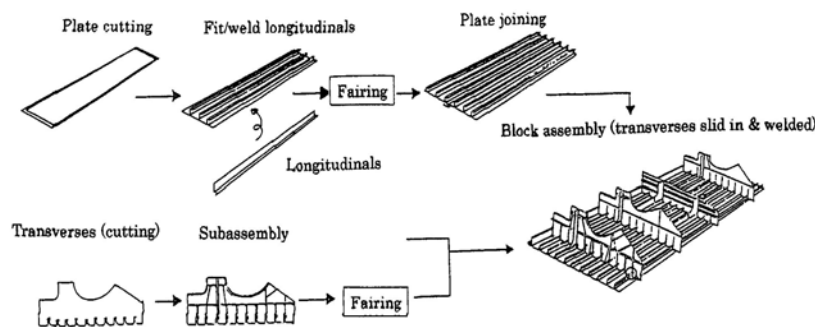


Fig. 1: Unit panel and slit construction, flat panel sub-assemblies

(Source: Nakayama, 1998)

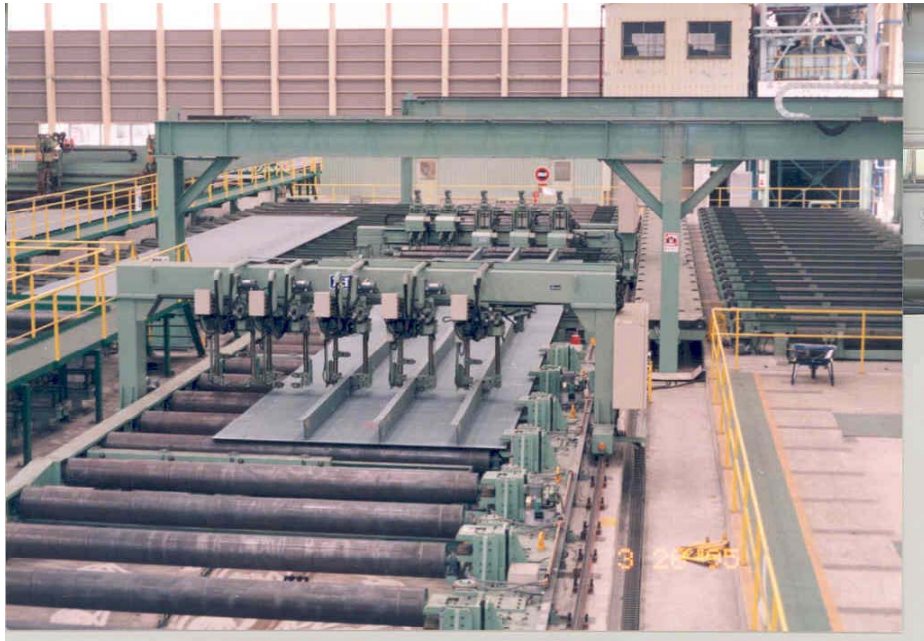


Fig. 2: Unit panel and slit construction – Automatic placement of longitudinals
(Photo courtesy of IHI Kure Shipyard)

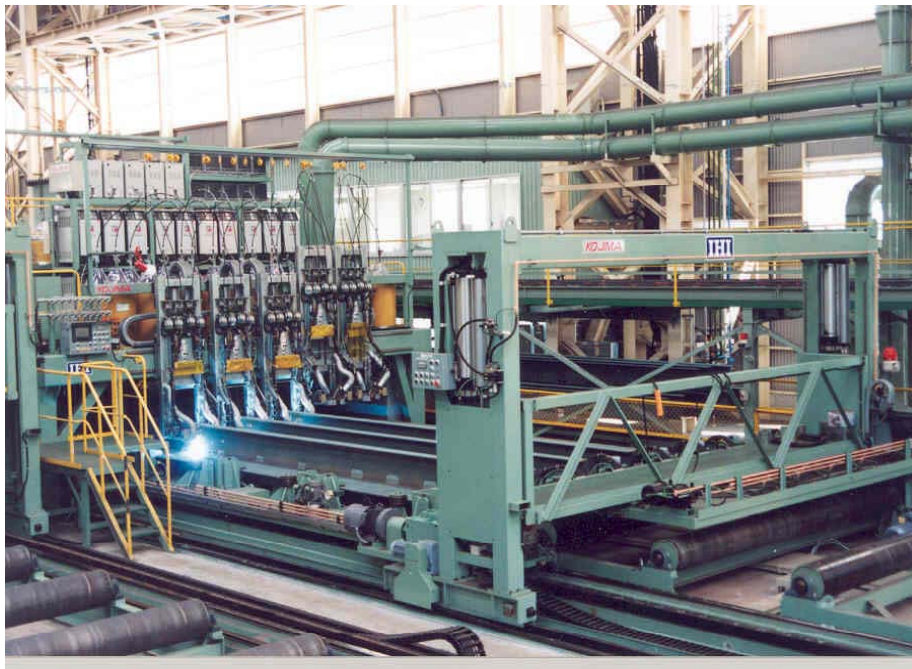


Fig. 3: Unit panel and slit construction – Automatic welding of longitudinals to single plate
(Photo courtesy of IHI Kure Shipyard)



Fig. 4: Unit panel and slit construction – Sliding on the transverses
(Photo courtesy of IHI Kure Shipyard)

FULLY AUTOMATED LINE HEATING

Line heating is the process of forming steel plates into curved shapes (as required for ship shell plates) by controlled heating and cooling. The process was developed in the 1950's at IHI. It requires a minimum of equipment, results in accurately formed plates, and is highly productive. It is used widely throughout the Japanese shipbuilding industry. There was a classic National Shipbuilding Research Program report on this subject (*Line Heating*, #0163, 1982).

Although line heating is highly effective, the Japanese shipbuilders have a business need to get around some of the limitations inherent in the technology. Most of these arise because line heating is a skilled manual craft practiced by experienced technicians who work individually using hand-held torches and tools. Knowing where and how to apply heat to achieve a given plate shape is dependent on know-how and intuition. Years of practice are required to attain a journeyman level of proficiency in this craft.

IHI has introduced a fully automatic line heating system into production operations at their Kure shipyard (Ishiyama and Tango 2000, Koenig et al 2002). This system, called 'IHI-Alpha,' takes plate offsets from the

shipyard's product modeling system and automatically calculates a heating procedure that is then applied to the plate at a numerically controlled workstation in the fabrication shop. The system requires no operator experience; in fact except for start-up it requires no operator. In addition, it is more repeatable and is significantly faster than the manual, craft-based system. The IHI-Alpha system is illustrated in Fig. 5.

Compared to IHI's manual line heating process, this new technology offers the following advantages:

- Reduction in production man-hours.
- Faster plate forming.
- Elimination of skilled shop-floor workers.

The reduction in production man-hours is dramatic. Using the IHI-Alpha system, highly complex curved shapes that formerly required two to three days of manual forming, now require just 5-6 hours shop time plus 2-3 hours of computer time to calculate the heating plan. Equally important to IHI is that the system eliminates the need to develop and retain the skills of experienced line heating technicians. Using the new technology, skill and judgment is transferred from the shop floor to the design office. A classic Taylorist or Fordist process improvement.

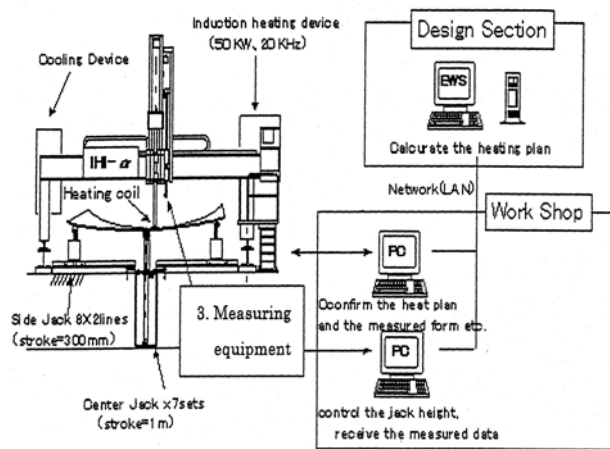


Fig. 5. Automatic line heating system
(Source: Ishiyama and Tango, 2000)

SUMMARY AND DISCUSSION

We reviewed the five mechanisms of lean production as given by Womack and Jones (1996), whose original book *The Machine that Changed the World* coined the term. We discussed how these mechanisms relate to Japanese shipbuilding practice. Summarizing them one by one:

Product value: Not an issue in the international merchant shipbuilding business, as ships are built to order under contract, and the requirements of the buyers are well defined.

Elimination of inessential operation from the value stream: As the Japanese shipyards have achieved remarkable results in this area continuously for over 50 years, they must be counted among the best (and earliest) exemplars of this principle. Japanese shipbuilders had achieved world-beating results here at a point when Toyota and the other car companies were barely viable. In the shipyards, some of the motivations and mechanisms pursued in the elimination of unnecessary steps have been lean; others more closely reflect the original principles of Frederick W. Taylor and Henry Ford.

Flow: In this respect, the Japanese shipyards arguably are equal in 'lean-ness' to the best manufacturers in any other industry worldwide. In the shipyards, both the production systems and the organizational structures are designed according to one-piece flow concepts.

Pull: This is a particularly interesting case. Japanese shipyards are different from automobile final assembly plants in this respect. Car factories build primarily to inventory but their internal production processes can, per the 'lean' literature, be organized by pull. In a Japanese shipyard, shipowners' orders 'pull' the final product but once the production schedule is established it is not allowed to vary for any reason. Upstream production goes ahead even when downstream problems occur, and there is no provision for workers to 'pull the cord' and stop the line.

Continuous pursuit of perfection: In this respect, Japanese shipyard business needs and performance outcomes match those of Toyota.

After considering the general applicability of these lean principles to ship production, we presented two examples of process improvements recently implemented in the Japanese shipbuilding industry. One case (unit panel and slit construction) was substantially consistent with lean principles and might make a good, concrete case study of lean thinking in action.

However, in the other instance (automated line heating), investment was made to speed up process throughput and reduce the company's dependence on skilled labor. This was done through engineering R&D and capital investment in dedicated machinery. Thus, automated line heating is an example of original Ford-style mechanization rather than lean thinking.

Discussion

Our consideration of the lean production automobile model and Japanese shipbuilding represents an initial exploration and discussion. However, our observations can suggest some tentative conclusions.

Are Japanese shipbuilders 'lean producers?' This depends on whether lean production is defined as a total, unified, Toyota-style system (as in Womack et al, 1991 or Womack and Jones, 1996), or a less specific menu of best practices. In current Japanese shipyard practice, the complete, Toyota-inspired lean package is not evident.

If a looser, more philosophical approach to 'lean' is pursued, then there are 'lean' concepts (e.g., flow, perfection) that are indeed rigorously applied in Japanese shipbuilding. But these were applied in Japanese shipbuilding before they appeared at Toyota. If the concept originated (or was manifested at an early date) in a shipyard, how instructive or appropriate is the use of a Toyota-based paradigm?

The term 'lean production' is not well known in Japanese shipbuilding, and we are not aware of any concerted effort on the part of Japanese shipbuilders to study Toyota or other firms in mass production industries. Japanese ship production practice represents a mixture of lean mechanisms and mechanisms not derived from 'lean.' Some recently introduced, cost-reducing

production process improvements in Japanese shipyards reflect 'lean thinking' while others are the result of more basic business principles dating back to Taylor or Ford (or before).

If we consider goals and achievements, the goal of lean production is cost reduction. Whether or not they employ specific 'lean' thought and mechanisms, the Japanese shipbuilding industry is one of the world's foremost masters of the art and science of cost control and cost reduction. For decades the industry has been aggressively boosting productivity and thereby lowering costs. Today, cost reduction is arguably the Japanese industry's paramount focus. Achievements in cost reduction seem to have accelerated in recent years. Among the world's three leading shipbuilding countries, Japan has by far the highest per unit labor costs. However, the unmatched productivity of the Japanese industry approximately makes up for this disadvantage and the net result is that Japanese shipbuilding has been able to maintain global competitiveness (Nagatsuka, 2002).

Which 'lean' mechanisms might be appropriate in other, non-Japanese shipbuilding environments? More in-depth study of exactly how these principles apply in various shipbuilding business environments might be useful. In the 1980's the International Motor Vehicle Program resulted in substantial dissemination of the lean production automobile model. Could a similar study of the shipbuilding industry, on the same scale, have a comparable effect?

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